Determination of the pressing parameters of spruce water-resistant plywood

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ABSTRACT: The paper summarizes results of operations aimed at determining the pressing parameters of spruce water-resistant plywood and testing the suitability of particular constructions of plywood. Constant and variable parameters were determined. In pressed plywood sheets, the shearing strength of gluing according to EW 100 and the coefficient of compressibility were determined. In pressing, heat transmission through the set of veneers was analyzed and effects of the moisture of veneers on heat transmission were tested. The percentage of resin hardening was also determined. Results were statistically analyzed. The dependence was determined of shearing strength, coefficient of compressibility and heat transmission on changes in pressing parameters. Results of the study consist in the proposal of pressing parameters for particular constructions of plywood.

Keywords: plywood; gluing strength; veneer; plywood construction; statistical evaluation

Since the beginning of human civilization, man has used a renewable resource, wood raw material, which is probably one of the most important products of the vegetable kingdom. Wood from felled trees caused some problems to users and processors; the most serious of the problems was the conversion of stems to forms suitable for construction or other purposes. These problems induced the need of new processing technologies for the manufacture of wood-based materials, e.g. veneers, plywood, solid glued products, agglomerated materials and other wood composites.

Wood becomes a shortage material all over the world; it must be imported for processing into industrial agglomerations and its price on world markets increases. Diminishing raw material resources and the shortage of natural wood lead to the increasing use of new materials with generally better properties more suitable for industrial production. These materials are characterized by large dimensions, uniformity of mechanical properties and greater resistance to external effects. Large-area materials are produced by pressing usually under increased temperatures from wood elements obtained by mechanical or other division.

According to the size of these detached parts it is possible to distinguish main types of large-area laminated materials:
- plywood materials,
- agglomerated materials.

Unlike particleboards and fibreboards plywood materials maintain the appearance of natural wood. By reason of high raw material requirements the manufacture of veneers and plywood materials shows considerable technical and technological development. The shortage of wood raw material, its decreasing quality and particularly its increasing price force the manufacturers of veneers and plywood sheets to use newer and more modern technologies enabling effective valorization in processing the wood raw material aimed at achieving higher aesthetic properties of wood.

Wood is characterized by a number of valuable properties explaining its broad and versatile use. Wood represents a firm but light material showing good heat insulation properties, it is able to tolerate

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a considerable load and to damp vibrations. Wood conducts the electrical current poorly not being liable to corrosion. It can be machined by means of cutting tools and joined using glues, nails or screws. Under dry conditions, it can be transported easily. Wood is characterized by resonance properties.

Wood shows, however, its drawbacks which decrease possibilities of the full utilization of its advantages. Dimensions of the wood raw material are given by the size of the stem and it is not possible to manufacture the material of larger areas from it without dividing it into smaller parts and then binding these parts together to a large-area material. Wood does not show sufficient hardness being anisotropic, i.e. it has different physical and mechanical properties in various directions. With the change in moisture content it changes its shape (dimensions) and properties. Mechanical properties of various tree species but also of the same species are different. Solid wood is subject to rot and does not resist the effect of high temperatures, fire and water. It includes defects (knots, cracks etc.) worsening its physical and mechanical properties.

The above-mentioned drawbacks can be eliminated to a great extent or removed by the physical/mechanical and chemical processing of wood into sheet and board materials. Larger dimensions can be achieved through the manufacture of rotary-cut veneers and their subsequent gluing to large-area sheets. Higher hardness of wood can be achieved by pressing under a high pressure. The restriction of anisotropic properties can be achieved by gluing veneer plies under a certain angle of wood fibres (plywood, laminated wood, etc.) when properties of wood in various directions of wood fibres are equalized. Fire and rot resistance can be increased by retardation and antiseptic treatment. Increase in water-resistance can be achieved using phenol-formaldehyde or melamine-formaldehyde adhesives, foils or special surface treatment.

Plywood materials have shown broad possibilities of their use in various fields thanks to their physical and mechanical properties.

- Furniture manufacture – decorative veneers are designed for veneered elements for cabinet, table and other furniture. Construction veneers are used for shaped veneers for the manufacture of seating furniture, for lamellas for the manufacture of spring grids. These materials are used for the manufacture of school furniture, decorative and construction elements of the interior furniture, etc.
- Wooden and combined constructions of dwelling and utility character, particularly panels of prefabricated houses, roof trusses, floors, partition walls, posts, tie beams, TJI beams, etc.
- Engineering constructions – used in combination with other materials, sarking, inner and outer facing, gables, stairs, etc.
- Formwork – system boarding, circular boarding, supporting elements of boarding, etc.
- Floors in industrial and storage halls, floors of elevated storeys, mezzanines, loading and arrival platforms, floors of scaffoldings, etc.
- Door manufacture – constructions of door wings including doorframe, ornamental veneering, door jackets, etc.
- Land means of transport – lorries, railway wagons, floors, walls and interiors of buses, trams, cars, trailers, caravans, superstructures of cars, etc.
- In industry – transport platforms, work platforms and tables, specially loaded parts, etc.
- Farm buildings – roofs, walls, inside lining, silos for fodder, fertilizers and cereals, farm vehicles
- Road signs and billboards, traffic signs, etc.
- Ships and yachts – decks, interior equipment taking into account aesthetic, strength, fire-technical properties, rescue boats, bridge boats, ships for the transport of liquid nitrogen, tankers, cooling transport premises
- Aircraft constructions – small sports, utility (e.g. farm) and transport planes – construction parts, sheathing, propellers
- Containers and packing for shipping particularly sea transport, hygienic areas, storage and distribution, pallets, cases, barrels, trays, etc.
- Foot bridges, sports ground equipment
- Toys, gaming machines, shell mouldings for cutting forms, shells for skateboard, etc.
- Sporting goods and equipment – floors of sports halls, winter stadiums, ping-pong tables, squash halls, sports halls, platform constructions, etc.
- Musical instruments – pianos, organs, stringed instruments, musical and loudspeaker boxes
- Stage and studio equipments with requirements for acoustic properties
- Crematory coffins – some parts of construction
- Various special products such as plywood pipes, laminated pressed wood for the manufacture of foundry models, etc.

According to their construction plywood materials are as follows: plywood (joinery, building, packaging, aircraft and laminated wood), core boards (blockboards, veneer-faced boards), sandwich boards (honeycomb panels, Jiko) and special materials (Parallam, Microllam, Intrallam, LVL, Europly); according to their shape there are flat and form ones (Hrázský, Král 2005a).

They can also be distinguished according to main quality characteristics, i.e. service life (for outdoor use and for the use in the internal dry environment), according to mechanical properties, surface appearance, methods of surface finish (unsanded, sanded, surface treated, coated).

Factor affecting the quality of a glued joint

Wood density. Strength properties of a glued joint increase with increasing density in the same kind of wood (Eisner et al. 1966). The width of annual rings in spruce is a good indicator for practice. Based on the width we can derive and assess the density of wood.

Earlywood and latewood. Studies carried out in pine have shown that the gluing quality is influenced whether it is a joint of "latewood-latewood" (L–L), "earlywood-earlywood" (J–J) or J–L. The highest strength was achieved in J–J.

Wood porosity. Shearing strength increases with increasing volume weight and thus decreasing porosity.

The direction of wood fibres in a glued area. Suchsland (1987) found that the depth of the adhesive penetration into wood was related to the length of fibres and to an angle between the fibres and the wood surface. The depth of penetration can be calculated. In spruce, the penetration increases with the increasing spread of adhesives and increasing angle of fibres.

Wood strength and swelling. Spruce plywood is not affected by various water baths before a shearing test to such an extent as beech plywood. It can be explained by the lower strength of spruce wood and smaller tangential swelling (Suchsland 1987). It was demonstrated by the results of shearing strength test after wetting for 1–72 hours at 20–100°C.

Effects of the content of natural resins. Wood of our conifers contains resins consisting of resin acids of a polar character. Therefore, it shows good affinity both to wood and to an adhesive (Eisner et al. 1966).

Surface quality according to Suchsland (1987):

– submicroscopic roughness (microfibrillar tissue structure),
– microscopic roughness (dimensions of cells, tracheids),
– technical roughness (annual ring structure).

He found that:

– the adhesion area and strength increased with increasing profile depth,
– the strength decreased from a certain profile depth.

The quality of rotary-cut veneers. The criteria of veneer quality are as follows: tensile strength across the fibre, mean depth of cracks and the frequency of cracks. In good-quality veneers, lower spread of adhesives was achieved at a higher strength of gluing (Král 2006).

Left and right side of veneers. Gluing tests in Norway birch demonstrated the best results in gluing "left side-left side", good results in "right side-left side" and bad results in "right side-right side". In spruce, no differences were found out (Kollmann 1975).

Veneer thickness. Veneers up to a thickness of 3.2 mm can be glued directly (Kollmann 1975). In thicker veneers, planing is suitable before gluing; a glued joint between two thinner veneer sheets is more often defective than a glued joint between a thin and a thick veneer sheet. With the increasing thickness of veneers the spread of a gluing mixture also increases.

Material moisture. Phenol-formaldehyde (PF) adhesives are extremely sensitive to the amount of moisture contained in veneers. Increased moisture extends the pressing period, increases the compression of plywood and decreases the viscosity of an adhesive spread, which results in deep penetration into wood and joints of poor quality.

Total moisture. Moisture conditions are very important for the quality of gluing. Through gluing, we bring further moisture into wood. After gluing, the actually existing moisture appears to be the sum of wood moisture before gluing and the moisture increment. In connection with the initial moisture of veneers and the amount of spread it usually ranges between 8 and 15%. Under conditions of higher moisture, damage to a glued joint can occur (open joints or blisters).

Temperature of veneers and adhesives. The initial temperature of veneers should be higher than or at least equal to the temperature of an adhesive. Under these conditions, vacuum is created in surface pores due to a rapid decrease in the air volume caused by a difference in temperatures, which supports the penetration of the adhesive to a greater depth and thereby the surface of a glued joint and mechanical adhesion increase. At a lower temperature of veneers than that of the adhesive a reverse process takes place when the volume of air from pores increases, small bubbles are created and then the air penetrates under pressure through the adhesive layer decreasing its adhesion and thus also the gluing strength. The greater the temperature difference, the more important the effect.

Adhesive reactivity is the rate of resole conversion to three-dimensional molecules, i.e. the condition of resite as a result of heat. The reactivity of PF adhesives can be increased by the addition of resorcinol, tanstuffs, hexamethylenetetramine etc. Sedliačik (1995) reduced the period of pressing in F – 20 adhesive by 1 min using a mimosa mixture at 150°C.

Adhesive viscosity is an important indicator of glue. An optimum viscosity for veneers thinner than 1.5 mm is 2,000–2,500 MPa/s and for veneers over 1.5 mm 2,500–4,000 MPa/s.

Adhesive dry matter. It is known that with increasing dry matter the rate of adhesive hardening also increases. At a temperature of 140°C and the dry matter difference 11% (58–47%) a difference in the time of hardening amounts to about 3 min. In this country, the PF adhesive dry matter ranges mostly about 50%. It is substantially lower abroad but extenders, fillers and other admixtures are used more frequently there.

Adhesive spread. The amount of gluing mixture spread in g/m^2 exerts a great effect on the strength of the glued joint.

Glued joint thickness. The layer of a spread gluing mixture dries up in the process of hardening reducing its volume, and thus stresses occur in the adhesive layer. Volume changes in phenolic adhesives amount to only 25%. There is an effort to preserve the minimum thickness of a glued joint ensuring the physical and mechanical properties of the joint.

Surface stress. Maximum shearing strength and maximum percentage of wood failure were demonstrated at surface stresses of 68.0 and 68.8 mN/m.

Contact angle. An increase in the quality of gluing with an increasing contact angle was noted, which contradicted a general view that a small contact angle was desirable. However, an interaction between the properties of wood and adhesive shows considerable effects.

Resin alkalinity. Shearing strength and percentage of wood failure were highest at pH 11. The value was largely dependent on the amount of NaOH in the reaction mixture.

Free phenol. With the decreasing content of free phenol the PF adhesive reactivity increases.

Pressing diagrams. At the beginning, they were simple. After reaching a certain value, the working pressure was maintained for a certain time, and it was decreased at the end of the pressing period. It is recommended to reduce the pressure in two stages: in the first from a maximum to 0.3–0.4 MPa and in the second from 0.3–0.4 MPa to zero. The duration of the first stage is 0.15–0.25 min. The duration of the second stage is dependent on the type of adhesive, pressing temperature, moisture content of the material and number of layers. For PF adhesives and moisture content of veneers up to 12%, 35–45 s is mentioned in three-plied plywood (birch, pine) at a temperature of 135–155°C and 80–90 s in multilayer plywood at a temperature of 135–137°C. The introduction of the manufacture of multilayer plywood brought about also changes in pressing diagrams. Multistage pressing programmes have been introduced abroad. Working pressures are decreased in several stages there. This procedure has brought about a decrease in the percentage of compression and the quality of production has been improved.

Specific pressure. It should ensure the good contact of glued surfaces. The rate of the used pressure is primarily dependent on the pressed woody species. Kafka (1989) mentions 1 MPa for softwood plywood, 1.2 MPa for combined plywood and 1.5 MPa for hardwood plywood.

Pressing temperature. For the full thermic hardening of phenolic resins a temperature of about 180°C is required. Temperatures 130–160°C used in practice give joints resistant to water although the resin has not fully hardened yet, the degree of hardening being, however, sufficient for quality bonding. Multi-component PF adhesives allow to decrease pressing temperatures to 120–125°C, e.g. Finnish adhesives Vatex-224 and Exter A. An addition of quebracho extract to phenol adhesives has been introduced in Finland.

Pressing period. The pressing period of laminated materials is dependent on many factors, the most important of them being the temperature of compression plates, working pressure, woody species, thickness of elements and of the product, kind of resin and viscosity of its solution etc. From the aspect of heat passage and temperature increment, it is important to differentiate the plate margins. The margin is a belt 7.5–10 cm wide along the plate periphery. Heat passage is slower there mainly at temperatures over 100°C (evaporation, heat dissipation). Calculation relationships are generally effective only for the central zones of plates not taking into account K_S. Because calculation relationships do not provide the guarantee of sufficiently accurate results, the measurement of temperature by means of thermocouples is generally used in sets of veneers to determine the temperature increment (and thus pressing periods) (Šteller 1995).

Objectives of the study

Problems of pressing plywood are rather complicated. Based on the results of research and practical operations new factors are found. The aim of the study was to determine pressing parameters of spruce water-resistant plywood for general use and to test the suitability of particular plywood constructions.

Results are applied immediately in practice, and thus we start from some practical data (e.g. tree species, veneer moisture, amount of spread, initial pressing periods, etc.). Possibilities were tested to intensify the process of pressing by changes in pressing temperature, pressing period and pressing diagrams.

The quality of gluing and the actual plywood thickness were decisive for assessing the suitability of some technological procedures of pressing. Results were evaluated statistically.

Basic operations were completed by the measurement of heat passage, determining the percentage of resin hardening, coefficient of compressibility, etc.

Results of the study consist in determining pressing parameters for specific pressures of spruce water-resistant plywood. These results are used in practice.

MATERIAL AND METHODS

In the experimental part of the paper, constant parameters were determined first and then variable parameters and the range of selection.

Constant parameters:

– PF resin P 5250; spread 150 g/m^2,

– spruce veneer 1.8 mm thick; moisture 5 ± 2%,

– plywood structure.

Nominal thickness (mm)	Number of layers
5	3
8	5
12	7
15	9
18	11

Variable parameters:

– pressing temperature 160°C; specific pressures 1, 1.2, 1.4 MPa,

– pressing temperature 150°C; specific pressure 1 MPa and pressing diagrams A, B, C

  – – (A) 1.2 MPa 50% pressing period; 0.8 MPa 50% pressing period – 1 min; 0.4 MPa 1 min

  – – (B) 1.4 MPa 1/3 pressing period; 0.7 MPa 1/3 pressing period; 0.2 MPa 1/3 pressing period

  – – (C) 1.2 MPa 50% pressing period; 0.6 MPa 50% pressing period – 1 min; 0.1 MPa – 1 min,

– pressing period – the starting period for each thickness was a pressing period designated by t used in practice. Next two pressing periods were determined as follows: $t_1 = t - 1'$ and $t_2 = t - 2'$. In construction 11×, at 150°C only time t was used with respect to the results found at 160°C.

The extent of the test

Gluing quality is crucial to assess pressing parameters. In the basic series of tests, 254 sheets were pressed in the laboratory and 2,520 specimens were tested (shearing strength in gluing) according to EN 314. The specimens were air-conditioned and exposed to EW-100 (gluing class 3) before the test.

Moreover, the coefficient of plywood compressibility, heat passage and the percentage of resin hardening were determined (Hrázský, Král 2005a).

RESULTS AND DISCUSSION

The course of a temperature increment in the last glued joint was determined by a copper-constantan thermocouple. At the thermocouple gradation and the actual measurement a connection was used with a comparative end.

Pressing temperature 160°C

The results of heat passage measurement show that an anticipated temperature of 130°C was achieved in constructions 3×, 5× and 7× at all working pressures earlier than in the shortest pressing period t_2. In construction 9×, a temperature of 130°C was achieved in all three pressing periods at P_3 pressure. At P_2 pressure, a temperature of 126–129°C was achieved within the limits of t, t_1, t_2 pressing periods and at P_1 pressure, a temperature of 121–126°C was achieved within the limits of t, t_1, t_2 pressing periods. In construction 11×, a temperature of 130°C was achieved at P_3 pressure earlier than after the shortest time t_2. At P_2 pressure, a temperature of 130°C was achieved at t (at t_1 – 129°C and at t_2 – 127°C), P_1 pressure was achieved at t – 123°C, t_1 – 121°C, t_2 – 120°C. Of all pressed sheets, only sheets 11× did not meet under the following combinations of pressing parameters: $P_1 - t_1$ (121°C), $P_1 - t_2$ (120°C), $P_2 - t_2$ (127°C). The rate of heat passage increases with increasing pressure, which is mainly related to a reduction in the effective depth of warming-through due to the greater compression of the set of veneers.

Pressing temperature 150°C

The anticipated temperature of 130°C at P_1 pressure in plywood constructions 3×, 5×, 7× was achieved in all three pressing periods t, t_1 and t_2. In plywood construction 9×, the following temperatures were achieved in the particular periods: t – 123°C, t_1 – 121°C, t_2 – 118°C. In plywood construction 11×, only period t was used and a temperature of 117°C

Table 1. Comparison of a theoretically calculated time necessary to achieve 130°C in the last glued joint (time in seconds)

Plywood construction	Theoretically calculated time		Virtually determined time			
			160°C			150°C
	160°C	150°C	P_1	P_2	P_3	P_1
3×	41	52	90	60	42	126
5×	134	165	144	114	84	270
7×	271	338	228	180	156	252
9×	458	556	–	612	456	–
11×	696	843	–	720	462	–

was achieved. All pressed sheets complied with requirements (a shearing test in the plane of the plywood complies with EV/-100). Comparison of the theoretically calculated time necessary to achieve 130°C in the last glued joint and results of practical measurements are given in Table 1.

Heat passage through the set of veneers of higher moisture

Heat passage was studied in plywood sets 11 × 1.8 mm, format 250 × 250 mm at the veneer moisture of 10 ± 2%. Other parameters were as follows: 150°C; 1 MPa; pressing period – after achieving 130°C in the last glued joint; adhesive spread 150 g/m^2. Heat passage at W = 10% is much slower than at W = 5%. A temperature of 117°C was reached after 12 min. W 5% was reached after 18 min and a temperature of 130°C after 22 min. Slowdown was noted particularly after exceeding 100°C. This temperature was attained at both veneer moistures after about 5 min, of course, in veneers W = 10% a temperature of 108°C was achieved after 12 min and 117°C after 18 min. Pressing period is extended by 50%. The temperature inside a bundle increases more slowly although the air heat conductivity is almost 23 times lower than the heat conductivity of water. During the gradual warming-through of the set of veneers a woody species changes its temperature together with water contained in wood and adhesive. At a temperature of 100°C, a part of moisture changes into vapour filling all spaces in wood and between veneer sheets. If there is no passage of vapours from the centre of the set pressed between pressing plates, then the vapour more and more increases its temperature, which increases the inner stress of vapours in the veneer set. Resistance of the vapour passage through any duct is directly proportional to the length of the path the vapour has to pass. Vapour from marginal parts of the veneer set passes to the ambient air and the vapour pressure decreases. Due to the pressure decrease evaporation stops at the expense of superheated water in the boiling point decreasing again during evaporation, which becomes evident particularly intensively as soon as a temperature of 100°C is achieved. Due to this evaporation partial losses of evaporation heat will occur. According to drying the marginal parts of the veneer set this process will transfer to the centre of the set, resistance for the vapour passage will increase, the amount of evaporated water and heat losses will decrease, and thus the temperature in the marginal part of the set will increase. The temperature of the central zone of the set at larger formats continuously increases to the temperature of pressing plates.

It has been found that in construction 3×, a temperature of 125–130°C in the last glued joint does not suffice to obtain a water-resistant joint after 108 s. In construction 11×, results demonstrated that temperatures 115, 117 and 120°C were sufficient for the creation of a water-resistant joint. Based on the results mentioned above it is possible to conclude that not only a certain temperature but also a certain time interval of the effect of the given temperature are necessary for the water-resistant hardening of a glued joint.

Table 2. The proportion of the veneer set thickness per glued joint

Construction	3×	5×	7×	9×	11×
Gross thickness of plywood (mm)	5.40	9.00	12.60	16.20	19.80
Number of glued joints	2.00	4.00	6.00	8.00	10.00
Thickness per 1 glued joint (mm)	2.70	2.25	2.10	2.03	1.98
Moisture (%)	11.50	12.80	13.30	13.60	13.80

It is possible to conclude:

– the rate of heat passage increases with the increasing working pressure (within a certain pressing temperature),
– the rate of heat passage decreases with the increasing moisture of the veneer set,
– to obtain water-resistant joints not only a certain temperature but also a certain interval of the effect of a certain temperature are necessary.

Coefficient of compressibility

In all pressed sheets, the coefficient of compressibility was determined. The values K_S given thereinafter represent a mean of six values (160°C) and of three values (150°C). The actual thickness of plywood given in an attached table is an important indicator.

The ČSN EN 635 standard prescribes parameters of allowable deviations for water-resistant plywood of gluing class 3.

Pressing temperature 160°C

The results of the analysis of variance inside particular constructions of plywood under P_1, P_2, P_3 pressures showed that a difference between variances was significant in all constructions. The same result was found in the analysis of variance between particular constructions of plywood at P_1 pressure. Testing the differences in arithmetical means demonstrated that there was a significant difference between particular means. Also testing the differences in arithmetical means at P_1 pressure between various constructions of plywood shows a statistically significant difference in the following combinations of plywood constructions at P_1 pressure (at $\underline{a}$ = 95% and $\underline{a}$ = 99%):

3×–9×	5×–9×	7×–9×
3×–11×	5×–11 ×	7×–11×

Certain regularity occurs there, namely plywood up to the number of 7 plies is compressed less than plywood 9× and 11×. Causes of these differences are elucidated in Table 2.

Table 2 shows that in veneer sets according to the number of plies we obtain different thickness of a veneer set corresponding to a glued joint and different aggregate moisture if we preserve constant conditions of production. These differences condition various values of the coefficient of compressibility.

Pressing temperature 150°C

Analysis of variance between particular constructions of plywood at P_1 pressure showed that differences were significant. Testing the differences in arithmetical means at P_1 pressure between various constructions of plywood did not bring so marked differences as at a pressing temperature of 160°C. On the significance level a = 95%, differences were found in the following constructions of plywood: 3×–7×, 3×–9×, 3×–11×, 5×–9×.

Due to the small number of measurements stepped pressing diagrams were not statistically evaluated. According to mean K_S it is possible to propose the following diagrams in particular constructions of plywood: 3× – C, 5× – A, 7× – A, 9× – C, 11× – A.

To achieve the given coefficient of compressibility plywood 7× (150°C, P_1, t) was pressed. The aim was to achieve the given value K_S 5%. Veneer sets were inserted into a press on the plates of which a thickness meter was fixed. Then the pressure was applied. After achieving the calculated value K_S the pressure was reduced in order not to increase the compression. Mean K_S = 6.45% was achieved as against K_S 10.07% (160°C, P_1) and K_S = 9.79 (150°C, P_1).

Effects of the moisture of veneers on the coefficient of compressibility. It was noted in the set 11 × 1.8 (150°C, P_1, 12 min, W = 10%). Mean K_S = 13.97%, i.e. an increase by 3.81% as against W = 5%.

Effects of a specific pressure on the coefficient of compressibility. Analysis of variance within particular plywood constructions at P_1, P_2 and P_3 pressures and 160°C showed that differences were statistically significant in all constructions.

Results of the analysis of variance between particular constructions of plywood at P_1 pressure and temperatures 150°C and 160°C showed statistically significant differences as well.

Testing the difference in arithmetical means was carried out within particular plywood constructions at P_1, P_2 and P_3 (160°C) – differences were statistically significant.

Results of testing the differences in arithmetical means at P_1 pressure are given in paragraphs relating to pressing temperatures. It is possible to conclude that:

– differences between coefficients of compressibility at working pressures P_1, P_2 and P_3 (160°C) are statistically significant,
– differences between arithmetical means of coefficients of compressibility of various plywood constructions at P_1 pressure are statistically significant more frequently at a higher temperature (160°C) than at a lower temperature (150°C),
– stepped pressing diagrams improve the quality of production (smaller number of vapour blisters) and reduce the coefficient of compressibility (in plywood 9× and 11×),
– the coefficient of compressibility can be intentionally controlled.

Table 3. Mean values of coefficients of compressibility at a pressing temperature of (160 ± 3)°C

Plywood construction	3×			5×			7×			9×			11×		
Specific pressure	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
Pressing period t	9.63	11.80	15.76	9.70	12.92	18.71	9.91	12.40	20.41	10.95	14.63	19.25	12.05	15.23	22.94
Pressing period t_1	9.50	13.03	15.35	9.51	12.70	17.15	10.08	12.31	18.92	18.28	15.49	20.44	11.46	14.54	20.91
Pressing period t_2	9.60	12.54	16.38	9.85	12.61	16.82	10.22	12.72	19.54	10.71	14.93	19.55	11.09	15.14	19.29
Mean K_S	9.58	12.48	16.16	9.63	12.74	17.56	10.07	12.48	19.62	11.31	15.02	19.75	11.53	14.93	21.05

Table 4. Mean values of coefficients of compressibility at a pressing temperature of (150 ± 3)°C

Plywood construction	3×				5×				7×				9×				11×			
Specific pressure or regime	P_1	*A*	*B*	*C*	P_1	*A*	*B*	*C*	P_1	*A*	*B*	*C*	P_1	*A*	*B*	*C*	P_1	*A*	*B*	*C*
Pressing period t	8.77	11.31	14.96	11.01	9.07	11.33	12.50	14.41	9.45	9.94	16.00	10.65	10.30	15.22	11.33	8.87	9.74	9.22	9.93	12.60
Pressing period t_1	9.27				10.10				10.20				11.45				11.97			
Pressing period t_2	8.11				8.60				9.72				9.65				8.77			
Mean K_S	8.72				9.26				9.79				10.47				10.16			

Table 5. Mean thickness of veneer sets and plywood at a pressing temperature of (160 ± 3)°C (mm)

Plywood construction		3×			5×			7×			9×			11×		
Specific pressure		P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
Pressing period t	Σh_i	5.52	5.47	5.54	9.09	9.18	9.41	12.86	12.86	12.93	16.52	16.58	17.08	20.29	20.48	20.22
	H	4.99	4.82	4.61	8.20	7.99	7.65	11.59	11.27	10.29	14.70	14.15	13.79	17.85	17.36	15.59
Pressing period t_1	Σh_i	5.37	5.59	5.52	9.23	9.34	9.33	12.80	12.96	12.98	16.74	16.77	17.01	20.42	20.89	20.38
	H	5.00	4.86	4.70	8.36	8.15	7.73	11.51	11.37	10.52	14.68	14.08	13.54	18.08	17.43	16.12
Pressing period t_2	Σh_i	5.48	5.57	5.59	9.39	9.32	9.25	12.88	12.83	12.83	16.47	16.58	17.00	20.41	20.38	20.16
	H	4.96	4.87	4.68	8.47	8.13	7.70	11.58	11.23	10.32	14.70	14.13	13.68	18.15	17.30	16.29
Mean	Σh_i	5.46	5.54	5.55	9.23	9.29	9.33	12.85	12.88	12.91	16.25	16.64	17.03	20.37	20.58	20.26
	H	4.98	4.85	4.66	8.34	8.09	7.69	11.56	11.29	10.30	14.69	14.12	13.67	18.03	17.36	16.00

Table 6. Mean thickness of veneer sets and plywood at a pressing temperature of (150 ± 3)°C (mm)

Plywood construction		3×				5×				7×				9×				11×			
Specific pressure or regime		P_1	A	B	C	P_1	A	B	C	P_1	A	B	C	P_1	A	B	C	P_1	A	B	C
Pressing period t	Σh_i	5.70	4.49	5.60	5.55	9.37	9.22	9.21	9.20	12.62	12.43	13.14	12.46	16.18	16.49	16.41	16.22	20.02	20.04	20.01	20.79
	H	5.20	4.86	4.77	4.94	8.52	8.19	8.05	7.60	11.43	11.14	11.04	11.15	14.52	13.98	14.55	14.78	18.07	18.19	18.01	18.17
Pressing period t_1	Σh_i	5.61				9.60				12.45				16.45				19.72			
	H	5.09				8.63				11.18				14.57				17.36			
Pressing period t_2	Σh_i	5.55				9.53				12.89				16.37				20.06			
	H	5.10				8.71				11.54				14.79				18.30			
Mean	Σh_i	5.62				9.50				12.55				16.33				19.93			
	H	5.13				8.62				11.42				14.63				17.77			

Mean values of coefficients of compressibility at various combinations of pressing parameters are given in Tables 3 and 4.

Mean thickness of veneer sets and plywood is given in Tables 5 and 6.

Shearing strength on the level of plywood layers

Pressing temperature 160°C

Remaining pressing parameters P_1, P_2, P_3 and t, t_1 t_2. During cutting the specimen sheets 11× disintegrated in combinations $P_1 - t_1$, $P_1 - t_2$, $P_2 - t_2$. In the remaining sheets, higher strength was achieved than required by the standard. Results of one- and two-factor analysis of variance within particular constructions demonstrated that differences were statistically insignificant in all cases.

Pressing temperature 150°C

Plywood pressed in the laboratory (P_1; t, t_1, t_2, in construction 11× only t). Plywood pressed in operation (P_1 and pressing diagrams C, A, A, C, A – arranged in the order of an increasing number of plywood plies; pressing period t, t_1, t_2 (at P_1) and t_2 in stepped pressing diagrams – in construction 11× only time t).

One-factor analysis of variance was carried out for plywood pressed in the laboratory (L) and in operation (P). Wood is a markedly heterogeneous material, and therefore it is possible to consider a difference between variances to be significant only if $F = 0.01$. Then, a difference from plywood sheets L in construction 5× and from sheets P in constructions 3× and 5× is significant.

Results of testing the difference in arithmetical means: in sheets L, a statistically significant difference was found in construction 5× ($t–t_2$ and $t_1–t_2$) and in construction 9× ($t–t_1$,). In sheets P, these statistically significant differences were found: 3× ($t–t_1$; $t_1–t_2$; $t–Ct_2$; $t_2–Ct_2$), 5× ($t–t_1$; $t–_2$; $t–At_2$, $t_1–At_2$) and 7× ($t–t_1$).

Summary

– at a pressing temperature of 160°C, only accidental difference was found between variances in all plywood constructions (except 11×),

– at a pressing temperature of 150°C, a difference occurred between variances only in sheets L in construction 5×,

– in stepped pressing diagrams, a decrease in shearing strength was found in sheets P in constructions 3× and 5× (the values markedly exceed requirements of standards),

– designed pressing parameters based on the results of shearing tests: pressing temperature 150°C and subsequently in particular plywood constructions: 3× ($P_1–t_2$ or $C–t_2$), 5× ($A–t_2$), 7× ($A–t_2$), 9× ($C–t_2$), 11× ($A–t$).

Determination of the percentage of PF resin hardening

The aim of studying the character of PF resins in the field of UV spectrum was to determine the amount of the insoluble proportion of a heat-hardened resin. Methods according to Chow (1967) should be used. However, the characteristics of extinction curves obtained in P 5250 did not make it possible to use the methodology. Therefore, evaluation of the insoluble proportion was carried out from extinctions measured at λ max. = 283 nm. Spectral analyses were carried out in water solutions using a Specord UV-VIS apparatus of Zeiss Co.

The following measurements were carried out:

– dependence was found of the concentration of adhesive water solutions on extinction at 283 nm,

– thermal condensation of a PF adhesive was carried out at 130, 150, 170°C for various times,

– measured values served for the calculation of regression lines of the dependence of the degree of hardening, solubility and extinction; plywood 3 × was pressed, pressing parameters (1.2 MPa; 130°C, 150°C, 170°C), 1'48'', 2'48'', 4'48'', 6'48''),

– dry shearing strength was determined in samples from the plywood and after AW-100 test, the percentage of resin hardening was assessed in a glued joint,

– the values of extinctions and corresponding percentage of resin hardening are given in Table 7.

Table 7. Values of extinctions and the percentage of resin hardening

Pressing time	Pressing temperature					
	130°C		150°C		170°C	
	E	(%)	E	(%)	E	(%)
1'48''					0.31	57
2'48''	0.87	0	0.31	51	0.28	60
4'48''	0.35	52	0.25	59	0.21	69
6'48''	0.26	62	0.21	64	0.17	74

Summary

– effects of extractive substances and veneers were measured, however, they did not show any effect on the actual measurements of extinctions of extracts from resins giving a zero value to extinction; the presence of wood does not affect measurements of the percentage of resin hardening,
– results of shearing strength tests and the percentage of hardening the PF resin in a glued joint show that the joint is sufficiently water-resistant at hardening the adhesive exceeding 51% determined according to the methodology,
– in plywood 3 ×, the joint was water-resistant after pressing periods: 30°C – 4'48'', 150°C – 2'48'', 170°C – 1'.

CONCLUSION

Results of the study are used in a particular plant in the large-scale production of coniferous water-resistant plywood. For the first time, multistage pressing diagrams of a new type were used. A method has been proposed and experimentally tested making it possible to decrease the coefficient of compressibility in multiply plywood and, at the same time, to reduce the occurrence of vapour blisters.

Through experimental measurements, the whole production spectrum of plywood constructions was proved in relation to their actual thickness.

Determination of the percentage of resin hardening demonstrated that the dry matter of a gluing mixture was not used effectively. It is necessary to use multi-component gluing mixtures with the reduced dry matter of an actual resin and to utilize fillers and extenders. It will result in the reduction of production costs and better technologies. Determination of pressing parameters and testing plywood constructions occurred simultaneously with the determination of prepressing parameters.

SUMMARY

The paper objective was to determine pressing parameters of spruce water-resistant plywood for general use and to test the suitability of actual plywood constructions.

The selected method of processing resulted from the scheduled objective of the study. Constant (PF resin F 5250, spread 150 g/m^2, spruce veneer 1.8 mm thick, veneer moisture 5%, plywood construction) and variable parameters were determined (pressing temperature, working pressure, pressing period, pressing diagrams). The following parameters were determined in pressed sheets: shearing strength of glued joints after EW-100 exposition and coefficient of compressibility. During pressing, heat passage through the set of veneers was studied. Other tests were also carried out, namely determination of the percentage of resin hardening, intentional control of the coefficient of compressibility, effects of veneer moisture on heat passage and coefficient of compressibility etc. The extent of basic tests was determined statistically and the results were also evaluated statistically.

The paper results in the proposal of pressing parameters for actual plywood constructions. Relationships were also determined between shearing strength, coefficient of compressibility and heat passage and changes in pressing parameters. Determination of the percentage of resin hardening has demonstrated that the adhesive dry matter is not used economically at present and, therefore, it is necessary to introduce multi-component gluing mixtures. Results of the study are applied in practice.

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Stanovení lisovacích parametrů smrkových vodovzdorných překližek

ABSTRAKT: Článek shrnuje výsledky práce, jejímž cílem bylo stanovit lisovací parametry smrkových vodovzdorných překližek a ověřit vhodnost jednotlivých konstrukcí překližek. Byly určeny konstantní a proměnné parametry. Na vylisovaných překližovaných deskách byla stanovena pevnost lepení ve smyku podle EW 100 a koeficient slisovatelnosti. Při lisování byl analyzován prostup tepla dýhovým souborem a ověřen vliv vlhkosti dýh na prostup tepla. Rovněž bylo stanoveno procento vytvrzení pryskyřice. Výsledky byly statisticky vyhodnoceny. Byla stanovena závislost smykové pevnosti, koeficientu slisovatelnosti a prostupu tepla na změnách lisovacích parametrů. Výsledkem práce je návrh lisovacích parametrů pro konkrétní konstrukce překližek.

Klíčová slova: překližka; pevnost lepení; dýha; konstrukce překližky; statistické vyhodnocení

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